P32702

TRACKING ERROR SIGNAL GENERATION DEVICE, OPTICAL DISC APPARATUS, TRACKING ERROR SIGNAL GENERATION METHOD AND TRACKING CONTROL METHOD

This non-provisional application claims priority under 35 U.S.C., §119(a), on Patent Application No. 2003-124046 filed in Japan on April 28, 2003, the entire contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION:

The present invention relates to a tracking error signal generation device, an optical disc apparatus, a tracking error signal generation method, and a tracking control method.

2. DESCRIPTION OF THE RELATED ART:

It has been conventionally known to use a tracking error signal generation device for generating a tracking error signal in an optical disc apparatus for recording information on or reproducing information from an optical disc. A tracking error signal is a signal for indicating whether or not a beam is moving along a track provided in an optical disc.

A conventional tracking error signal generation device generates a tracking error signal as follows.

An optical beam emitted by a laser is split into a main beam, a first sub beam and a second sub beam by diffraction grating. The main beam, the first sub beam and the second sub beam are converged onto an optical disc by an objective lens. The main beam, the first sub beam and the second sub beam are reflected by the optical disc, and the reflected main beam, first sub beam and second sub beam are detected by a light detector.

In more detail, the light detector includes a two-portion main beam detector, a two-portion first sub beam detector, and a two-portion second sub beam detector. The two-portion main beam detector detects the main beam and generates a differential signal. The two-portion first sub beam detector detects the first sub beam, and generates a differential signal. The two-portion second sub beam detector detects the second sub beam and generates a differential signal.

A main beam push-pull signal generator generates a main beam push-pull signal based on the differential signal generated by the two-portion main beam detector.

A sub beam push-pull signal generator generates a sub beam push-pull signal based on the differential signal generated by the two-portion first sub beam detector and the differential signal generated by the two-portion second sub beam detector. In more detail, the sub beam push-pull signal generator generates a sub beam push-pull signal by adding the differential signal generated by the two-portion first sub beam detector and the differential signal generated by the two-portion second sub beam detector.

Next, the sub beam push-pull signal is amplified at an appropriate gain ratio as necessary, and the amplified sub beam push-pull signal is subtracted from the main beam push-pull signal. Thus, a tracking error signal is generated.

The conventional tracking error signal generation device generates a tracking error signal in this manner.

Accordingly, even if the objective lens is displaced and thus the main beam push-pull signal and the sub beam push-pull signal each obtain a DC offset, the DC offset is deleted from the tracking error signal by subtracting the sub beam push-pull signal from the main beam push-pull signal as disclosed in, for example, Japanese Laid-Open Publication No. 61-94246.

However, the amplitude of the tracking error signal may undesirably fluctuate.

For example, when an optical disc is eccentrically provided, the amplitude of the tracking error signal is reduced.

When the objective lens is displaced, the main beam push-pull signal is also displaced from the reference value.

Hereinafter, the case where the optical disc is eccentrically provided will be described.

An optical disc, which is rotated by a spindle motor, has a hole at the center thereof to which the spindle motor is attached. The hole is provided such that the center of the hole matches the center of the optical disc, namely, the center of a plurality of tracks formed spirally or concentrically.

However, the center of the optical disc may be undesirably deviated from the center of the hole, in which case the optical disc is rotated eccentrically.

Hereinafter, a tracking error signal when the optical

disc is rotated normally, i.e., not eccentrically, will be described with reference to Figures **9A** and **9B**. Then, a tracking error signal when the optical disc is rotated eccentrically will be described with reference to Figures **10A** and **10B**.

Figure **9A** shows a schematic view illustrating the relationship between the tracks and the scanning direction of a main beam **M**, a first sub beam **S1** and a second sub beam **S2** when the optical disc is rotated normally.

The optical disc has tracks concentrically or spirally formed. The tracks are provided such that adjacent tracks are parallel to each other.

As shown in Figure **9A**, the distance between the center of the optical spot formed of the first sub beam **S1** and the center of the optical spot formed of the main beam **M** is 1/2 of the track pitch. Similarly, the distance between the optical spot formed of the center of the second sub beam **S2** and the center of the optical spot formed of the main beam **M** is 1/2 of the track pitch.

The first sub beam **S1** is directed to a position at the center between the track irradiated by the main beam **M** and a track which is adjacent and outer to the track.

The second sub beam **S2** is directed to a position at the center between the track irradiated by the main beam **M** and a track which is adjacent and inner to the track.

A center line **900** represents the direction in which the main beam **M** scans the optical disc. In Figure **9A**, the

center line **900** and the tracks are parallel to each other.

Figure **9B** is a waveform diagram illustrating the main beam push-pull signal and the sub beam push-pull signal as the main beam **M** moves along the tracks in the case where the optical disc is rotated normally.

In Figure **9B**, "Mpp" refers both to a main beam push-pull signal based on the main beam **M** and an amplitude thereof, "Spp1" refers both to a differential signal generated by the two-portion first sub beam detector and an amplitude thereof, and "Spp2" refers both to a differential signal generated by the two-portion second sub beam detector and an amplitude thereof. Spp1 + Spp2 is the sub beam push-pull signal. The horizontal axis represents the position of the main beam **M**.

A tracking error signal TE is obtained by the following expression.

$$TE = Mpp - K \times (Spp1 + Spp2)$$

where K is a prescribed constant.

When the optical disc is rotated normally, the phase of the differential signal Spp1 generated by the two-portion first sub beam detector is the same as the phase of the differential signal Spp2 generated by the two-portion second sub beam detector. The two signals are not deviated in phase from each other. In this state, the sub beam push-pull signal, i.e., Spp1 + Spp2, has an amplitude of E.

The tracking error signal is generated by multiplying

the sub beam push-pull signal by the prescribed constant K and then subtracting the multiplication result from the main beam push-pull signal.

Next, with reference to Figures **10A** and **10B**, a tracking error signal when the optical disc is rotated eccentrically will be described.

Figure **10A** shows a schematic view illustrating the relationship between the tracks and the scanning direction of the main beam **M**, the first sub beam **S1** and the second sub beam **S2** when the optical disc is rotated eccentrically.

As shown in Figure **10A**, when the optical disc is rotated eccentrically, the first sub beam **S1** is deviated from the center between the track irradiated by the main beam **M** and the track which is adjacent and outer to the track in accordance with the rotating angle of the optical disc. Similarly, the second sub beam **S2** is deviated from the center between the track irradiated by the main beam **M** and the track which is adjacent and inner to the track in accordance with the rotating angle of the optical disc.

In Figure **10A**, a center line **1000** is not parallel to the tracks, and a portion of the first sub beam **S1** and a portion of the second sub beam **S2** are directed to a track **1001**.

Figure **10B** is a waveform diagram illustrating the main beam push-pull signal and the sub beam push-pull signal in the case where the optical disc is rotated eccentrically.

In Figure **10B**, Mpp" refers both to a main beam

push-pull signal based on the main beam **M** and an amplitude thereof, "Spp1" refers both to a differential signal generated by the two-portion first sub beam detector and an amplitude thereof, and "Spp2" refers both to a differential signal generated by the two-portion second sub beam detector and an amplitude thereof. Spp1 + Spp2 is the sub beam push-pull signal. The horizontal axis represents the position of the main beam **M**.

In the case where a portion of the first sub beam **S1** and a portion of the second sub beam **S2** are directed to a track **1001** as shown in Figure **10A**, the phase of the differential signal Spp1 is deviated with respect to the phase of the differential signal Spp2 as shown in Figure **10B**.

Here also, a tracking error signal TE is obtained by the following expression.

$$TE = Mpp - K \times (Spp1 + Spp2),$$

where K is a prescribed constant.

When the optical disc is rotated eccentrically, the phase of the differential signal Spp1 is deviated with respect to the phase of the differential signal Spp2. Accordingly, where the amplitude of the sub beam push-pull signal, i.e., Spp1 + Spp2, is R, the amplitude R is smaller than the amplitude E of the sub beam push-pull signal described above with reference to Figure **9B**.

As described above, a tracking error signal is generated by multiplying the sub beam push-pull signal by

the prescribed constant K and then subtracting the multiplication result from the main beam push-pull signal. Therefore, when the amplitude of the sub beam push-pull signal is smaller, an appropriate tracking error signal cannot be generated.

When the amplitude of the sub beam push-pull signal is reduced, the open loop gain of the tracking control system is reduced, which makes the tracking control system unstable.

The conventional tracking error signal generation device has the following problem in addition to the problem that the amplitude of the tracking error signal fluctuates.

Recently, it has been desired to increase the memory capacity of optical discs. In order to meet this desire, it has been proposed to provide an optical disc with a plurality of information faces. In such an optical disc, information can be recorded on or reproduced from the plurality of information faces by directing an optical beam from a prescribed direction.

When the information recorded on a prescribed information face is reproduced, focusing control is performed such that the optical beam is converged onto the prescribed information face. Tracking control is performed such that the optical beam moves along the tracks of the prescribed information face.

While the information recorded on the prescribed information face is reproduced, an optical beam passing through the prescribed information face may be undesirably reflected by an information face different from the

prescribed information face and is incident on the light detector.

Generally in a tracking error signal generation device, a light amount of a sub beam is about 1/10 of the a light amount of a main beam. A light amount of the sub beam reflected by a prescribed information face is smaller than a light amount of the main beam reflected by the prescribed information face. Therefore, when a main beam passing through the prescribed information face is reflected by an information face different from the prescribed information face and is incident on the light detector, the light amount thereof which is incident on the two-portion first sub beam light detector and the two-portion second sub beam light detector is not negligible.

The light amount of the main beam which is incident on the two-portion first sub beam light detector and the two-portion second sub beam light detector varies in accordance with, for example, the distance between the prescribed information face and the different information face being changed. The distance between a track or portions thereof of the prescribed information face and the corresponding track or portions thereof of the different information face of the optical disc varies. Therefore, while the optical disc is rotating, the light amount of the main beam reflected by the different information face changes by a cycle of several hundred hertz.

A portion of the main beam reflected by the different information face acts as an external disturbance to the sub beam push-pull signal, resulting in the tracking error signal including an offset component. Therefore, the tracking

cannot be appropriately controlled, which may undesirably deteriorate the recording and/or reproduction quality.

SUMMARY OF THE INVENTION

According to one aspect of the invention, a tracking error signal generation device includes a splitting and convergence section for splitting an optical beam into a main beam and a sub beam and converging the main beam and the sub beam onto an optical disc; a two-portion main beam detection section for detecting the main beam reflected by the optical disc; a main beam push-pull signal generation section for generating a main beam push-pull signal based on a differential signal which is output from the two-portion main beam detection section; a two-portion sub beam detection section for detecting the sub beam reflected by the optical disc; a sub beam push-pull signal generation section for generating a sub beam push-pull signal based on a differential signal which is output from the two-portion sub beam detection section; a displacement amount detection section for detecting a displacement amount of the main beam push-pull signal from a reference value based on the main beam push-pull signal and the sub beam push-pull signal; and a tracking error signal generation section for generating a tracking error signal by correcting either the main beam push-pull signal or the sub beam push-pull signal based on the displacement amount detected by the displacement amount detection section.

In one embodiment of the invention, the displacement amount detection section adds the main beam push-pull signal and the sub beam push-pull signal and detects the addition result as a displacement amount of the main beam push-pull

signal from the reference value.

In one embodiment of the invention, the tracking error signal generation section generates a tracking error signal by correcting the main beam push-pull signal based on a low frequency component of a signal representing the displacement amount detected by the displacement amount detection section.

In one embodiment of the invention, the optical disc has at least one track. The splitting and convergence section includes an objective lens for converging the main beam and the sub beam onto the optical disc. The tracking error signal generation device further includes a driving section for driving an objective lens displacement section for displacing the objective lens in a direction substantially perpendicular to the at least one track by outputting a driving signal to the objective lens displacement section. The displacement amount detection section includes a first objective lens displacement amount detection section for adding the main beam push-pull signal and the sub beam push-pull signal and detecting the addition result as an objective lens displacement amount, and a second objective lens displacement amount detection section for detecting an objective lens displacement amount based on the driving signal. The tracking error signal generation section generates the tracking error signal by correcting the main beam push-pull signal based on a low frequency component of a signal showing the objective lens displacement amount detected by the first objective lens displacement amount detection section and a high frequency component of a signal showing the objective lens displacement amount detected by the second objective lens displacement amount detection section.

In one embodiment of the invention, the second objective lens displacement amount detection section includes an equivalent filter having a characteristic which is equivalent to a characteristic of the objective lens displacement section and detecting the objective lens displacement amount based on the driving signal.

According to another aspect of the invention, an optical disc apparatus includes a tracking error signal generation device including: a splitting and convergence section for splitting an optical beam into a main beam and a sub beam and converging the main beam and the sub beam onto an optical disc having at least one track, the splitting and convergence section including an objective lens for converging the main beam and the sub beam onto the optical disc, a two-portion main beam detection section for detecting the main beam reflected by the optical disc, a main beam push-pull signal generation section for generating a main beam push-pull signal based on a differential signal which is output from the two-portion main beam detection section, a two-portion sub beam detection section for detecting the sub beam reflected by the optical disc, a sub beam push-pull signal generation section for generating a sub beam push-pull signal based on a differential signal which is output from the two-portion sub beam detection section, a displacement amount detection section for detecting a displacement amount of the main beam push-pull signal from a reference value based on the main beam push-pull signal and the sub beam push-pull signal, and a tracking error signal generation section for generating a tracking error signal by correcting either the main beam push-pull signal or the sub beam push-pull signal based on the displacement amount detected by the

displacement amount detection section; an objective lens displacement section for displacing the objective lens in a direction substantially perpendicular to the at least one track; a transfer section for transferring the objective lens displacement section in a direction substantially perpendicular to the at least one track; a transfer control section for controlling the transfer section based on the displacement amount detected by the displacement amount detection section; and a tracking control section for controlling the objective lens displacement section based on the tracking error signal.

In one embodiment of the invention, the tracking error signal generation section further includes a driving section for driving the objective lens displacement section by outputting a driving signal to the objective lens displacement section. The displacement amount detection section includes a first objective lens displacement amount detection section for adding the main beam push-pull signal and the sub beam push-pull signal and detecting the addition result as an objective lens displacement amount, and a second objective lens displacement amount detection section for detecting an objective lens displacement amount based on the driving signal. The tracking error signal generation section generates the tracking error signal by correcting the main beam push-pull signal based on a low frequency component of a signal showing the objective lens displacement amount detected by the first objective lens displacement amount detection section and a high frequency component of a signal showing the objective lens displacement amount detected by the second objective lens displacement amount detection section. The transfer control section controls the transfer section based on the low frequency component

and the high frequency component.

According to still another aspect of the invention, a tracking error signal generation method includes the steps of splitting an optical beam into a main beam and a sub beam and converging the main beam and the sub beam onto an optical disc; detecting the main beam reflected by the optical disc by a two-portion main beam detection section; generating a main beam push-pull signal based on a differential signal which is output from the two-portion main beam detection section; detecting the sub beam reflected by the optical disc by a two-portion sub beam detection section; generating a sub beam push-pull signal based on a differential signal which is output from the two-portion sub beam detection section; detecting a displacement amount of the main beam push-pull signal from a reference value based on the main beam push-pull signal and the sub beam push-pull signal by a displacement amount detection section; and generating a tracking error signal by correcting either the main beam push-pull signal or the sub beam push-pull signal based on the displacement amount detected by the displacement amount detection section.

According to still another aspect of the invention, a tracking control method includes the steps of splitting an optical beam into a main beam and a sub beam and converging the main beam and the sub beam onto an optical disc having at least one track by an objective lens; detecting the main beam reflected by the optical disc by a two-portion main beam detection section; generating a main beam push-pull signal based on a differential signal which is output from the two-portion main beam detection section; detecting the sub beam reflected by the optical disc by a two-portion sub

beam detection section; generating a sub beam push-pull signal based on a differential signal which is output from the two-portion sub beam detection section; detecting a displacement amount of the main beam push-pull signal from a reference value based on the main beam push-pull signal and the sub beam push-pull signal by a displacement amount detection section; generating a tracking error signal by correcting either the main beam push-pull signal or the sub beam push-pull signal based on the displacement amount detected by the displacement amount detection section; controlling a transfer section for transferring an objective lens displacement section for displacing the objective lens in a direction substantially perpendicular to at least one track based on the displacement amount detected by the displacement amount detection section; and controlling the objective lens displacement section for displacing the objective lens in a direction substantially perpendicular to the at least one track based on the tracking error signal.

As described above, according to a tracking error signal generation device of the present invention, the displacement amount detection section detects a displacement amount of the main beam push-pull signal from the reference value based on the main beam push-pull signal and the sub beam push-pull signal. The tracking error signal generation section generates a tracking error signal by correcting either the main beam push-pull signal or the sub beam push-pull signal based on the displacement amount. Therefore, the tracking error signal can be generated in the state where an offset component caused by displacement of the main beam push-pull signal from the reference value is cancelled.

According to a tracking error signal generation

device of the present invention, a tracking error signal is generated by correcting the main beam push-pull signal based on a low frequency component of a signal representing the displacement amount detected by the displacement amount detection section. Therefore, a tracking error signal which has the external disturbance of the sub beam push-pull signal cancelled therefrom is obtained. The external disturbance of the sub beam push-pull signal is caused by the main beam reflected by an information face which is different from the target information face of the optical disc.

According to a tracking error signal generation device of the present invention, the first objective lens displacement amount detection section adds the main beam push-pull signal and the sub beam push-pull signal to detect a displacement amount of the objective lens, and the second objective lens displacement amount detection section detects a displacement amount of the objective lens based on the driving signal for driving the objective lens displacement section. A tracking error signal is generated by correcting the main beam push-pull signal based on a low frequency component of a signal representing the displacement amount detected by the first objective lens displacement amount detection section and a high frequency component of a signal representing the displacement amount detected by the second objective lens displacement amount detection section. Therefore, a tracking error signal which has the external disturbance of the sub beam push-pull signal cancelled and is accurate in a high frequency range is obtained. The external disturbance of the sub beam push-pull signal is caused by the main beam reflected by an information face which is different from the target information face of the optical disc.

A tracking error signal generation device according to the present invention includes an equivalent filter having a characteristic which is equivalent to that of an objective lens displacement section. Therefore, an objective lens displacement amount can be detected based on a driving signal for driving the objective lens displacement section.

An optical disc apparatus according to the present invention includes a transfer section for transferring the objective lens displacement section in a direction substantially perpendicular to the tracks, and a transfer control section for controlling the transfer section based on the output from the objective lens displacement amount detection section. Therefore, the objective lens displacement amount can be reduced.

An optical disc apparatus according to the present invention includes an objective lens displacement section for displacing the objective lens in a direction substantially perpendicular to the tracks, a transfer section for transferring the objective lens displacement section in a direction substantially perpendicular to the tracks, and a transfer control section for controlling the transfer section based on a low frequency component of the output signal from a first objective lens displacement amount detection section and a high frequency component of the output signal from the second objective lens displacement amount detection section. Therefore, the influence of the objective lens displacement amount can be reduced over a broad frequency range.

Thus, the invention described herein makes possible

the advantages of providing a tracking error signal generation device and a tracking error signal generation method for generating an appropriate tracking error signal by detecting a displacement amount of a main beam push-pull signal, obtained from a main beam, from a reference value, based on the main beam push-pull signal and a sub beam push-pull signal obtained from sub beams, and then correcting either the main beam push-pull signal or the sub beam push-pull signal based on the displacement amount; an optical disc apparatus including such a tracking error signal generation device; and a tracking control method for performing tracking control using the tracking error signal generated by such a tracking error signal generation device and method.

These and other advantages of the present invention will become apparent to those skilled in the art upon reading and understanding the following detailed description with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram illustrating an optical disc apparatus including a tracking error signal generation device according to a first example of the present invention;

Figure 2 is a block diagram illustrating an optical head in the tracking error signal generation device in the first example;

Figure 3 is a schematic view illustrating the relationship between tracks and optical beams for explaining the first example;

Figure **4** is a block diagram illustrating a light detector in the optical head in the first example;

Figure **5** is a waveform diagram for illustrating push-pull signals in the first example;

Figure **6** is a block diagram illustrating a computation circuit in the first example;

Figure **7** is a block diagram illustrating an optical disc apparatus including a tracking error signal generation device according to a second example of the present invention;

Figure **8** is a block diagram illustrating a computation circuit in the second example;

Figure **9A** is a schematic diagram showing the relationship between the tracks and the scanning direction of the main beam and the sub beams where the optical disc is rotated normally in a conventional tracking error signal generation device;

Figure **9B** is a waveform diagram illustrating a main beam push-pull signal and a sub beam push-pull signal where the optical disc is rotated normally in the conventional tracking error signal generation device;

Figure **10A** is a schematic diagram showing the relationship between the tracks and the scanning direction of the main beam and the sub beams where the optical disc is rotated eccentrically in the conventional tracking error signal generation device; and

Figure **10B** is a waveform diagram illustrating a main beam push-pull signal and a sub beam push-pull signal where the optical disc is rotated eccentrically in the conventional tracking error signal generation device.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, the present invention will be described by way of illustrative examples with reference to the accompanying drawings.

(Example 1)

Figure **1** is a block diagram illustrating an optical disc apparatus **10** having a tracking error signal generation device **20** according to a first example of the present invention.

The optical disc apparatus **10** includes the tracking error signal generation device **20** for generating a tracking error signal for an optical disc **107**, a tracking driving circuit **204**, a spindle motor **206** for rotating the optical disc **107** at a prescribed rotation rate, an objective lens actuator **308**, and a transfer motor driving circuit **302**.

The tracking error signal generation device **20** includes an optical head **100**, a main beam push-pull signal generation circuit **300**, a sub beam push-pull signal generation circuit **301**, a displacement amount detection section **40**, and a tracking error signal generation section **50**.

The tracking error signal generation device **20** may further include a preamplifier **201** for amplifying a signal

which is output from the optical head **100**.

The tracking error signal generation device **20** may further include a driving section **60** for driving the tracking driving circuit **204**.

The optical disc **107** has at least one information face.

In the case where the optical disc **107** has two or more information faces, the optical head **100** moves a beam spot to a target information face so as to record information on the target information face or reproduce information recorded on the target information face.

With reference to Figure **2**, the optical head **100** of the optical disc apparatus **10** will be described in more detail.

Figure **2** is a block diagram illustrating the optical head **100** according to the first example of the present invention.

The optical head **100** includes a splitting and conversion section **30** for splitting an optical beam into a main beam and sub beams and converging the main beam and the sub beams onto the optical disc **107**, and a light detector **111**.

The optical head **100** may further include a hologram device **109** and a cylindrical lens **110**.

The splitting and conversion section **30** includes a semiconductor laser **101**, a diffraction grating **102**, a beam

splitter **103**, a light collection lens **104**, a reflective mirror **105**, and an objective lens **106**.

An optical beam emitted by the semiconductor laser **101** is split by the diffraction grating **102** into a main beam **M** corresponding to a zero order light component, a first sub beam **S1** corresponding to a plus first order light component, and a second sub beam **S2** corresponding to a minus first order light component. The main beam **M**, the first sub beam **S1** and the second sub beam **S2** are transmitted through the beam splitter **103**.

Next, the main beam **M**, the first sub beam **S1** and the second sub beam **S2** are collected to the reflective mirror **105** by the light collection lens **104**.

The main beam **M**, the first sub beam **S1** and the second sub beam **S2** are reflected by the reflective mirror **105** and then converged onto a prescribed information face of the optical disc **107** by the objective lens **106**. In more detail, the main beam **M** is converged onto a desired track of the optical disc **107** by the objective lens **106**. The first sub beam **S1** is converged by the objective lens **106** onto a position which is away in an outer direction from the main beam **M** by a prescribed distance. The second sub beam **S2** is converged by the objective lens **106** onto a position which is away in an inner direction from the main beam **M** by a prescribed distance.

The main beam **M**, the first sub beam **S1** and the second sub beam **S2** will be described.

Figure 3 is a schematic view illustrating the

relationship between the tracks of the optical disc **107** and the main beam **M**, the first sub beam **S1** and the second sub beam **S2** in the first example.

The first sub beam **S1** is directed to a position which is advanced in the scanning direction and deviated in an outer direction by about 1/2 track pitch with respect to the main beam **M**. The second sub beam **S2** is directed to a position which is behind in the scanning direction and deviated in an inner direction by about 1/2 track pitch with respect to the main beam **M**.

The tracks are provided parallel to each other. The main beam **M**, the first sub beam **S1** and the second sub beam **S2** move on the optical disc **107** in the scanning direction.

Returning to Figure **2**, the optical disc **100** will be described.

The main beam **M**, the first sub beam **S1** and the second sub beam **S2** are reflected by the optical disc **107**. The main beam **M**, the first sub beam **S1** and the second sub beam **S2** reflected by the optical disc **107** pass through the objective lens **106**, reach the reflective mirror **105**, are reflected by the reflective mirror **105** and are guided to the light collection lens **104**.

The main beam **M**, the first sub beam **S1** and the second sub beam **S2** which have passed through the light collection lens **104** are reflected by the beam splitter **103**, pass through the cylindrical lens **109** and the hologram device **110** sequentially and are detected by the light detector **111**.

The light detector **111** will be described in detail.

Figure **4** is a block diagram illustrating the light detector **111**.

The light detector **111** includes a two-portion main beam detector **111a**, a two-portion first sub beam detector **111c**, and a two-portion second sub beam detector **111e**.

The two-portion main beam detector **111a**, the two-portion first sub beam detector **111c** and the two-portion second sub beam detector **111e** are each divided into two portions in a radial direction of the optical disc **107**.

In more detail, a surface of the two-portion main beam detector **111a** includes a light receiving surface **A** and a light receiving surface **B**. The two-portion main beam detector **111a** generates a differential signal which represents the difference between a light amount detected by the light receiving surface **A** and a light amount detected by the light receiving surface **B**.

A surface of the two-portion first sub beam detector **111c** includes a light receiving surface **C** and a light receiving surface **D**. The two-portion first sub beam detector **111c** generates a differential signal which represents the difference between a light amount detected by the light receiving surface **C** and a light amount detected by the light receiving surface **D**.

A surface of the two-portion second sub beam detector **111e** includes a light receiving surface **E** and a light receiving surface **F**. The two-portion second sub beam detector **111e**

generates a differential signal which represents the difference between a light amount detected by the light receiving surface **E** and a light amount detected by the light receiving surface **F**.

Returning to Figure 1, the optical disc apparatus **10** will be described in more detail.

The optical head **100** outputs the differential signal generated by the two-portion main beam detector **111a**, the differential signal generated by the two-portion first sub beam detector **111c**, and the differential signal generated by the two-portion second sub beam detector **111e** to the preamplifier **201**.

The preamplifier **201** amplifies the differential signals generated by the two-portion main beam detector **111a**, the two-portion first sub beam detector **111c** and the two-portion second sub beam detector **111e**. Then, the preamplifier **201** outputs the amplified differential signal generated by the two-portion main beam detector **111a** to the main beam push-pull signal generation circuit **300**, and outputs the amplified differential signal generated by the two-portion first sub beam detector **111c** and the amplified differential signal generated by the two-portion second sub beam detector **111e** to the sub beam push-pull signal generation circuit **301**.

The main beam push-pull signal generation circuit **300** generates a main beam push-pull signal based on the differential signal generated by the two-portion main beam detector **111a**.

The main beam push-pull signal generation circuit **300** includes a computation amplifier (not shown), which generates a main beam push-pull signal Mpp having the relationship represented by expression 1.

$$Mpp = (A - B) \;..... \;(1),$$

where A represents the light amount detected by the light receiving surface **A** and B represents the light amount detected by the light receiving surface **B**.

The sub beam push-pull signal generation circuit **301** generates a sub beam push-pull signal based on at least one of the differential signal generated by the two-portion first sub beam detector **111c** and the differential signal generated by the two-portion second sub beam detector **111e**.

For example, the sub beam push-pull signal generation circuit **301** generates a sub beam push-pull signal by adding the differential signal generated by the two-portion first sub beam detector **111c** and the differential signal generated by the two-portion second sub beam detector **111e**.

The sub beam push-pull signal generation circuit **301** includes a computation amplifier (not shown), which generates a sub beam push-pull signal Spp having the relationship represented by expression 2. "Spp" refers both to a sub beam push-pull signal and an amplitude thereof.

$$Spp = (C + E) - (D + F) \;..... \;(2),$$

where C represents the light amount detected by the light receiving surface **C**, D represents the light amount

detected by the light receiving surface **D**, E represents the light amount detected by the light receiving surface **E**, and F represents the light amount detected by the light receiving surface **F**.

The displacement amount detection section **40** detects a displacement amount of the main beam push-pull signal Mpp from the reference value based on the main beam push-pull signal Mpp and the sub beam push-pull signal Spp.

The displacement amount detection section **40** may include an objective lens displacement amount detection circuit **305** for detecting a displacement amount of the objective lens **106**.

The displacement amount detection section **40** includes a computation amplifier (not shown), which detects a displacement amount detection signal LS having the relationship represented by expression 3. The displacement amount detection signal LS represents a displacement amount of the main beam push-pull signal from the reference value. The displacement amount of the main beam push-pull signal from the reference value is a displacement amount associated with, for example, the displacement amount of the objective lens, the eccentricity of the objective lens, and the tilt of the optical disc **107**.

$$LS = G \times (Mpp + \alpha \times Spp) \quad ..... (3),$$

where G is, for example, 0.5. α is a constant determined by the ratio between the light amount of the main beam and the light amount of the sub beams.

α is set such that the value of Mpp and the value of $\alpha \times$ Spp are substantially equal to each other.

As described above, the main beam push-pull signal Mpp obtains a DC offset component when being displaced from the reference value. The displacement amount detection signal LS corresponds to the DC offset amount.

Similarly, the sub beam push-pull signal Spp obtains a DC offset component when the main beam push-pull signal Mpp is displaced from the reference value. The displacement amount detection signal LS also corresponds to the DC offset amount.

The tracking error signal generation section **50** generates a tracking error signal by correcting either the main beam push-pull signal Mpp and the sub beam push-pull signal Spp based on the displacement amount detected by the displacement amount detection section **40**.

The tracking error signal generation section **50** may include a subtraction circuit **306** for subtracting the displacement amount signal LS from the main beam push-pull signal Mpp.

The tracking error signal generation section **50** includes a computation amplifier (not shown), which generates a tracking error signal TE having the relationship represented by expression 4 or 4'.

$$TE = Mpp - LS \quad \ldots\ldots (4)$$
$$TE = Spp - LS \quad \ldots\ldots (4')$$

As shown, the tracking error signal TE is a signal obtained by removing a DC offset component of the main beam push-pull signal Mpp or the sub beam push-pull signal Spp generated by the main beam push-pull signal Mpp being displaced from the reference value.

In expression 3, G = 0.5. The value of G may be adjusted such that the DC offset component of the tracking error signal TE is zero when the displacement amount of the main beam push-pull signal from the reference value is changed in advance. In one embodiment of the present invention, the objective lens **106** may be displaced such that the DC offset component of the tracking error signal TE is zero when the objective lens **106** is displaced in advance. Such an arrangement allows the DC offset component caused by the main beam push-pull signal being displaced from the reference value, or caused by the objective lens **106** being displaced in the one embodiment, to be accurately removed even when the characteristics of the optical head are changed.

The tracking error signal TE generated by the tracking error signal generation section **50** is input to the driving section **60**.

The driving section **60** may include a DSP (digital signal processor) **203**.

The DSP **203** converts the tracking error signal TE into a digital signal. The DSP **203** further performs addition and/or multiplication of the digital signal by a built-in core processor so as to realize digital filter computation processing for phase compensation or gain compensation.

The DSP **203** again converts the digital signal, which has been computed in a prescribed manner, into an analog signal by a built-in D/A converter, and outputs the analog signal to the tracking driving circuit **204**.

The tracking driving circuit **204** current-amplifies the analog signal to drive the objective lens actuator **308** as a tracking actuator in the optical head **100**. The objective lens actuator **308** displaces the objective lens **106** in a direction substantially perpendicular to the tracks of the optical disc **107**, and thus the main beam **M** moves along the tracks.

The displacement amount detection section **40** outputs the displacement amount detection signal LS to the DSP **203**.

The DSP **203** converts the displacement amount detection signal LS into a digital signal. The DSP **203** performs addition and/or multiplication of the digital signal by a built-in core processor so as to realize digital filter computation processing for phase compensation or gain compensation.

The DSP **203** converts the signal obtained by a prescribed computation into an analog signal again by a built-in D/A converter, and outputs the analog signal to the transfer motor driving circuit **302**.

The transfer motor driving circuit **302** current-amplifies the analog signal to drive a transfer motor **304**. The transfer motor **304** transfers the objective lens actuator **308** in a direction substantially perpendicular to the tracks of the optical disc **107**. Thus, the optical head

100 is controlled such that the displacement amount of the main beam push-pull signal from the reference value is zero.

Figure **5** is a waveform diagram for illustrating the main beam push-pull signal Mpp and the sub beam push-pull signal Spp in the first example.

Figure **5** shows the main beam push-pull signal Mpp and the sub beam push-pull signal Spp when the main beam **M**, the first sub beam **S1** and the first sub beam **S2** cross a plurality of tracks.

Section (a) shows a cross-section of the optical disc **107**.

Waveform (b) shows the main beam push-pull signal Mpp.

Waveform (c) shows the sub beam push-pull signal Spp.

In waveforms (b) and (c), the solid line represents the waveform where the main beam push-pull signal is not displaced from the reference value. The dotted line represents the waveform where the main beam push-pull signal is displaced from the reference value. The horizontal axis represents the relationship between the main beam **M** and the tracks. The vertical axis represents the levels of the main beam push-pull signal Mpp and the sub beam push-pull signal Spp.

In waveforms (b) and (c), the vertical one-dot chain lines represent the main beam **M** at the centers of the tracks. On the optical disc **107**, the first sub beam **S1** and the second

sub beam **S2** are directed to the positions which are deviated by 1/2 track pitch from the main beam **M**. Therefore, the main beam push-pull signal Mpp and the sub beam push-pull signal Spp are deviated in phase with respect to each other by 180 degrees.

In the case where the main beam push-pull signal is displaced from the reference value, the main beam push-pull signal Mpp and the sub beam push-pull signal Spp have the same polarity of DC offset components. The amounts of the DC offset components are in proportion to the displacement amount of the main beam push-pull signal Mpp from the reference value. Accordingly, the sine wave component is removed by adding the main beam push-pull signal Mpp and the sub beam push-pull signal Spp. Thus, the displacement amount detection signal LS corresponding to the displacement amount of the main beam push-pull signal from the reference value can be obtained.

This will be described using expressions.

The main beam push-pull signal Mpp is represented by expression 5.

$$Mpp = \sin(2 \times \pi \times X/P) + k \times Q \quad ..... \quad (5)$$

Similarly, the sub beam push-pull signal Spp is represented by expression 6.

$$Spp = -\sin(2 \times \pi \times X/P) + k \times Q \quad ..... \quad (6)$$

In expressions 5 and 6, X corresponds to the horizontal axis of Figure **5**, i.e., the position of the main

beam **M**, and P represents the track pitch.

In expressions 5 and 6, it is assumed that the amplitudes of the main beam push-pull signal Mpp and the sub beam push-pull signal Spp are adjusted in advance so as to be equal to each other for the sake of simplicity. In expressions 5 and 6, Q represents the displacement amount of the main beam push-pull signal Mpp from the reference value, and k is a constant representing the DC offset component with respect to the displacement amount Q of the main beam push-pull signal Mpp from the reference value.

Accordingly, the displacement amount detection signal LS can be represented by expression 7 based on the relationship among expressions 3, 5 and 6.

$$LS = G \times 2 \times K \times Q \;..... \;(7)$$

When G = 0.5, the displacement amount detection signal LS can be represented by expression 8.

$$LS = k \times Q \;..... \;(8)$$

Accordingly, the tracking error signal TE can be represented by expression 9 based on the relationship among expressions 4, 5 and 8.

$$TE = \sin(2 \times \pi \times X/P) \;..... \;(9)$$

The tracking error signal TE can also be represented by expression 9' based on the relationship among expressions 4', 6 and 8.

$$TE = -\sin(2 \times \pi \times X/P) \quad ..... \quad (9')$$

As shown in expression 9 or 9', the DC offset component of the main beam push-pull signal from the reference value is removed.

In the above description, the tracking error signal TE is generated by the subtraction circuit **306** in the tracking error signal generation section **50**. The tracking error signal generation section **50** may include another computation circuit instead of the subtraction circuit **306**. Hereinafter, an embodiment in which a computation circuit generates an objective lens displacement amount detection signal (also represented by the letters "LS") which shows an objective lens displacement amount will be described. The objective lens displacement amount is a displacement amount of the objective lens in the direction in which an optical beam crosses the tracks.

Figure **6** is a block diagram of a computation circuit **310** in the tracking error signal generation section **50** according to the first example of the present invention.

The computation circuit **310** includes a low pass filter (LPF) **400** and a subtraction circuit **401**.

The low pass filter **400** is connected to an input terminal **403** for receiving an objective lens displacement amount detection signal LS. The low pass filter **400** extracts a low frequency component from the objective lens displacement amount detection signal LS, and outputs the low frequency component to the subtraction circuit **401**.

The subtraction circuit **401** is connected to the input terminal **402** for receiving the main beam push-pull signal Mpp.

The subtraction circuit **401** subtracts the low frequency component of the objective lens displacement amount detection signal LS from the main beam push-pull signal Mpp, and outputs the subtraction result to the output terminal **404**.

The output terminal **404** is connected to the DSP **203** in the driving circuit **60** (Figure 1).

By including the low pass filter **400**, the computation circuit **310** can remove the influence of a fluctuation component of the sub beam push-pull signal Spp, which is caused by a portion of the main beam **M** reflected by an information face which is different from the target information face being incident on the two-portion first sub beam detector **111c** and the two-portion second sub beam detector **111e**. As described above, such an undesirable phenomenon occurs due to, for example, a change in the distance between the information faces. Owing to the influence of the fluctuation component being removed, an accurate objective lens displacement amount detection signal LS can be generated.

In the above description, the sub beam push-pull signal generation circuit **301** generates the sub beam push-pull signal Spp based on both the differential signal generated by the two-portion first sub beam detector **111c** and the differential signal generated by the two-portion second sub beam detector **111e**. The present invention is not

limited to this.

The sub beam push-pull signal generation circuit **301** may generate the sub beam push-pull signal Spp based on either the differential signal generated by the two-portion first sub beam detector **111c** or the differential signal generated by the two-portion second sub beam detector **111e**.

According to the first example, the tracking error signal TE is generated based on the displacement amount of the main beam push-pull signal Mpp from the reference value. Therefore, even when the main beam push-pull signal Mpp is displaced from the reference value, tracking control can be performed in the state where the offset component caused by the displacement amount of the main beam push-pull signal Mpp from the reference value is cancelled.

(Example 2)

Figure **7** is a block diagram illustrating an optical disc apparatus **10A** including a tracking error signal generation device **20A** according to a second example of the present invention.

The elements in the optical disc apparatus **10A** which are identical to the elements in the optical disc apparatus **10** described with reference to Figure **1** in the first example bear identical reference numerals thereto, and the description thereof will be omitted to avoid redundancy.

In the second example, the case where the main beam push-pull signal Mpp is displaced from the reference value by the displacement of the objective lens **106** will be described in detail.

The elements in the tracking error signal generation device **20A** which are identical to the elements in the optical disc apparatus **20** described with reference to Figure **1** in the first example bear identical reference numerals thereto, and the description thereof will be omitted to avoid redundancy.

The tracking error signal generation device **20A** includes a displacement amount detection section **40A**. The displacement amount detection section **40A** includes an objective lens displacement amount detection circuit **305**, an equivalent filter **420**, and a computation circuit **422**. The equivalent filter **420** is a filter having a transfer function equal to that of the objective lens actuator **308**.

A tracking driving circuit **204A** outputs a signal, which is identical to or corresponds to the signal to be output to the objective lens actuator **308**, to the equivalent filter **420**.

The equivalent filter **420** generates a signal representing a displacement amount of the objective lens **106**. This signal is represented as an objective lens displacement amount detection signal LS2.

The equivalent filter **420** outputs the objective lens displacement amount detection signal LS2 to the computation circuit **422**.

The objective lens displacement amount detection circuit **305** outputs an objective lens displacement amount detection signal LS to the computation circuit **422**.

The computation circuit **422** detects an objective lens displacement amount detection signal LS3 based on the objective lens displacement amount detection signal LS and the objective lens displacement amount detection signal LS2, and outputs the objective lens displacement amount detection signal LS3 to the subtraction circuit **306**.

The subtraction circuit **306** generates a tracking error signal TE based on the objective lens displacement amount detection signal LS3 and the main beam push-pull signal Mpp. The tracking error signal TE is input to the DSP **203** in the driving circuit **60**.

The operation of the optical disc apparatus **10A** hereafter is the same as that of the optical disc apparatus **10** described above with reference to Figure **1** in the first example.

The computation circuit **422** also outputs the objective lens displacement amount detection signal LS3 to the DSP **203**. Based on the objective lens displacement amount detection signal LS3, the DSP **203** controls the transfer motor driving circuit **302** such that the transfer motor driving circuit **302** drives a transfer motor **304**.

Figure **8** is a block diagram of the computation circuit **422**.

The computation circuit **422** includes a low pass filter (LPF) **601**, a high pass filter (HPF) **602**, and an addition circuit **604**.

An input terminal **600** is connected to the objective lens displacement amount detection circuit **305**. An input terminal **603** is connected to the equivalent filter **420**.

The output terminal **605** is connected to the subtraction circuit **306**.

The objective lens displacement amount detection signal LS which is input from the input terminal **600** has a low frequency component extracted therefrom by the low pass filter **601**, and the low frequency component is input to the addition section **604**.

The objective lens displacement amount detection signal LS2 which is input from the input terminal **603** has a high frequency component extracted therefrom by the high pass filter **602**, and the high frequency component is input to the addition section **604**.

The addition circuit **604** adds the low frequency component of the objective lens displacement amount detection signal LS and the high frequency component of the objective lens displacement amount detection signal LS2, and outputs the addition result to the output terminal **605** as the objective lens displacement amount detection signal LS3.

Using the low frequency component of the objective lens displacement amount detection signal LS, the influence of a fluctuation component of the sub beam push-pull signal Spp, which is caused by a portion of the main beam **M** reflected by an information face which is different from the target information face being incident on the two-portion first sub beam detector **111c** and the two-portion second sub beam

detector **111e**, is removed. (As described above, such an undesirable phenomenon occurs due to, for example, a change in the distance between the information faces.) Thus, an accurate objective lens displacement amount detection signal LS3 can be generated. By using the high frequency component of the objective lens displacement amount detection signal LS2, an objective lens displacement amount detection signal LS3 which is accurate even in a high frequency range can be generated.

The transfer function of the equivalent filter **420** and the characteristics of the actual objective lens actuator **308** are easily varied especially in a low frequency range by a temperature change or the like. By using the objective lens displacement amount detection signal LS in a low frequency range, an objective lens displacement amount detection signal LS3 which is accurate in all frequency ranges, can be generated.

Various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims be broadly construed.